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Individual variance in responsiveness to early computerized mathematics intervention

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ABSTRACT

We examined the effects of short, intensive computerized intervention in early number skills for kindergarteners with poor addition skills (below 1.5 *SD*). The mathematical content of the software was hierarchically organized, starting from one-to-one correspondence, comparing and ordering, and proceeding via number concept and counting to basic addition. The results showed positive within-group effects for basic addition (Wilcoxon *ES* (r) = .59), verbal counting (.56), and the Number Sets Test (.45; see Geary, Bailey, & Hoard, 2009). The effects remained stable over a 9-week follow-up period. However, there was no significant between-group difference in terms of gain scores as compared to a wait-list control group. Based on game-log data, individual variance in responsiveness to the intervention was analyzed. Even though the findings suggest that adaptive, hierarchically organized content could provide effective support for some children with poor early number skills, more specific instruction and feedback system are needed in individualizing interventions.

1. Introduction

Basic arithmetic (i.e., addition and subtraction skills) is an important predictor for later school mathematics achievement above and beyond the influence of intelligence (Duncan et al., 2007; Geary, 2011a; Geary, Hoard, & Bailey, 2012). Difficulties in basic arithmetic and fact retrieval are very persistent (Geary, 2011b), and they constitute a core feature of mathematics difficulties (MDs) (Gersten, Jordan, & Flojo, 2005). Accumulated knowledge about the development of early number skills as a basis for arithmetic has helped to advance means of early identification and support (Butterworth, 2005; Morgan, Farkas, & Wu, 2009). However, there is still a need to examine effective, evidence-based intervention methods (Butterworth, Varma, & Laurillard, 2011; Jordan & Levine, 2009), especially among kindergarteners with poor early number skills (performance below 10th percentile; Morgan et al., 2009; Murphy, Mazzocco, Hanich, & Early, 2007).

Early arithmetic skill seems to develop via different hierarchical modules of sub-skills. In this regard, approximate magnitude discrimination is the innate skill of subitizing small sets of objects and quickly differentiating which of the two sets of objects is the larger when the difference between the quantities is significant enough (Geary, 2013; Dehaene, 2011). The ability to recite number words evolves later with the development of expressive language skills, which thus enables meaningful counting (Krajewski & Schneider, 2009). After that, the link between the number words, quantities and symbols becomes precise (Geary, 2013; Krajewski & Schneider, 2009). This developmental step is required for describing the exact amount of quantities exceeding the subitizing range. Furthermore, an explicit number system, including an understanding of the relationships between numbers, is the next vital step for composing and decomposing, and thus, basic arithmetic skills (cf. Geary, 2013; Krajewski & Schneider, 2009). Von Aster (2000) has noted that individual development is also dependent on the maturation of semantic, verbal, and visual/symbolic modules, which are all necessary for calculation skills.

Due to the diversity of the deficits associated with MDs (e.g., Rubinsten & Henik, 2009), as well as the heterogeneity among individuals with MDs (e.g., Geary, 2004; Jordan, Hanich, & Kaplan, 2003; Von Aster & Shalev, 2007), there is a call for tailored interventions (Dowker, 2001; Geary, 2011b; Slavin & Lake, 2008), and continuous evaluation and identification of children who are not responding to support (Fuchs, Fuchs, & Compton, 2012). Therefore, adaptive intervention programs with dynamic, simultaneous assessment tools could be beneficial in identifying children with (or at-risk for) MDs, and for assisting teachers in planning individualized support.

A well-planned computer-assisted intervention (CAI) offers several possibilities for tailored practice (Seo & Bryant, 2009; Slavin & Lake, 2008), even though the main trend in terms of the effectiveness of CAI on number skills has been suggested to be in decline in recent decades

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(Cheung & Slavin, 2013). The factors behind CAI's positive effects on arithmetic development are challenging to identify due to variations among the target group's characteristics, group sizes, practiced numerical content and the instructional components, and the interventions' intensiveness in previous studies (see Table 1). In order to further develop the use of computers in learning, it is important to establish the specific components needed for effective, tailored intervention.

The core components of effective numerical intervention for children with (or at-risk for) MDs include explicit instructions; repetitive training in basic concepts; step-by-step proceeding; early success; immediate corrective, continuous, and cumulative feedback; and a motivating environment with which to maintain task-orientation (Baker, Gersten, & Lee, 2002; Fuchs et al., 2008; Gersten et al., 2009). Basic skills should be addressed before more complex ones (Dowker, 2001; Sarama & Clements, 2009), and sub-skills should be integrated rather than addressed separately (Fuchs et al., 2012). Further, the relationship between non-symbolic and symbolic notations should be emphasized (Griffin, 2004; Van Luit & Schopman, 2000). However, it seems that previous CAIs for arithmetic have mainly consisted of drill-based practice used for automatizing fact retrieval (see Table 1). Despite generally positive results, the stability of improvements stemming from the intervention is rarely reported. Nonetheless, Kucian et al. (2011) and Schoppek and Tulis (2010) have demonstrated the delayed effects of a short-term intervention that utilized a variety of mathematics content (see descriptions in Table 1).

There is no pre-existing evidence concerning the effects of gradually enhancing children's development of early number skills on learning arithmetic. In addition to group-level intervention effects, we wanted to evaluate individual performance during practice. Therefore, the study goals were: 1) to investigate the group-level effects of short and intensive intervention with a GraphoGame Math program (GGM; see description in Section 2.4.) and to assess the stability of any effects; 2) to contrast the intervention participants' gain scores with the performance level of a wait-list control group; and 3) to evaluate the responsiveness to GGM intervention at an individual level by analyzing the game-log data.

2. Method

Kindergarten teachers from 24 different day care centers in southern Finland were each asked to nominate two children from their group as candidates most in need of extra mathematics intervention. With their parents' permission, the children ($n = 48$) participated in assessments and computer-assisted intervention. All *48* children were individually tested to determine their early number skills. For ethical reasons, all the children were included in the intervention, even though the assessments indicated that the group of candidates included false positives. Participants were randomized into either 1) a GGM group ($n = 24$) that took part in GraphoGame Math practice during the first intervention period and had no practice during the second intervention period; or 2) a control group ($n = 24$) that had no extra practice during the first intervention period and participated in another numerical practice during the second intervention period. All participants were native speakers of Finnish.

2.1. Study participants

Of the *48* participants, *21* children fulfilled the criteria for poor addition skills (1.5 *SD* below the normative age level; below 7th percentiles) and were thus included in the analyses. The inclusion criterion was being unable to solve more than three simple addition problems (e.g., 2 + 1, 1 + 3, 3 + 2) in a time-limited task, as compared to the age-level mean score of 18 out of 45. The reference data had been collected by research assistants for another study one month prior to when the data collection for the current study was carried out (*reference sample n* = 77; *mean age* = 74.2 months, *SD* = 3.6). A sub-sample of *13* children (*4* boys and *9* girls; each from different day care centers) formed the GGM group (*mean age* = 78.6 months, *SD* = 5.4). One participant was not present for the third assessment due to illness. The missing data point was replaced by adding the mean gain score of the GGM group (the difference between the third and second assessments) to the child's score in the second assessment. This did not have an effect on the statistical significance of the findings. A sub-sample of *8*

Table 1
Descriptions of the trained contents in computer-assisted intervention studies of basic arithmetic.

Study	n	Age	Status	Duration	Training sessions	Description of the training	Effect
Baroody et al. (2012)[a]	28	5.58	at-risk[d]	19 weeks	20 + 20 × 30 min	Subitizing, enumeration, numeral recognition, transcoding and addition + addition (add-0/1)	+
Baroody et al. (2013)[a]	64	6.5	at-risk[d]	20 weeks	20 + 20 × 30 min	Transcoding, verbal counting, object counting, numerical relations, written numbers, arithmetic + addition (add-1/near doubles)	+
Christensen and Gerber (1990)	60	8.80	LD[e]	2 weeks	13 × 6 min	Drilling of single-digit addition facts	+
Fuchs et al. (2006)	33	6–7	at-risk MD[d] + RD	18 weeks	50 × 10 min	Retrieving addition and subtraction facts	+
Hativa and Shorer (1989)	211	8–11	low SES	Semester	3 times a week	Mixed types of arithmetical contents	−
Kraus (1981)[b]	19	7–8	TA	2 weeks	5 + 5 × 1 min	Filling the missing addends to addition combinations	+
Kucian et al. (2011)[b]	32	9.5	DD	13 weeks	25 × 15 min	Locating numbers of dots, digits, sums and differences to number line	++
Käser et al. (2013)[b]	32	7–11	MD	12 weeks	30 × 20 + 30 × 20 min	Number representation, varied types of addition and subtraction tasks	+
Mevarech and Rich (1985)	376	8–11	LA	Semester	Once a week	Mixed types of arithmetical contents	+
Obersteiner et al. (2013)	147	6.91	TA	4 weeks	10 × 30 min	Two versions of Number Race (c.f., Wilson, Dehaene et al. 2006)	+
Okolo (1992)	41	9–12	LD	9 weeks	4 × 20 min + 15 min	Mapping presented responds for addition or multiplication facts	+
Schoppek and Tulis (2010)	110	8.7	TA	10 weeks	7 × 60 min	Solving arithmetical equations and word problems (addition, subtraction, multiplication, division), number comparison, number line	+
Schoppek and Tulis (2010)	94	9.1	TA	10 weeks	7 × 45 min	Described above	++
Shin et al. (2006)	46	7–8	Middle SES	18 weeks	3–4 × 15 min a week	Drilling of addition, subtraction or their mixed combinations	+
Trifiletti, Frith, and Armstrong (1984)	21	9–15	LD[d] + MD	Semester	40 min a day	Mathematics readiness, addition, subtraction, multiplication, division and fraction	+
Wilson, Dehaene, Dubois, and Fayol (2009)[c]	53	5.6	Low SES	14 weeks	6 + 4 × 20 min	Number Race: Approximate comparison between quantities, number symbols and/or addition and subtraction facts	−
Wilson, Revkin, et al. (2006)	9	7–9	LA[f]	10 weeks	20 × 30 min	Number Race: described above	+

Note. Age = Mean age in years (as originally reported). LD = learning difficulties. MD = mathematics difficulties. RD = reading difficulties. SES = socioeconomic status. TA = typically achieving. DD = developmental dyscalculia. LA = low achieving. Effect = immediate (+) and long-term effects (++) on arithmetic.
[a]Training started with manual games. [b]Training operated at homes. [c]Training mixed with reading software. [d]Cut-off point (not always reported) below 25; [e]16; [f]37 percentiles.